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$$\lambda_{max} = \frac{2900}{400} \approx 7.2 \mu \text{. } \exists \text{ both } CO_2 + H_2O \text{ absorption features here.}$$

Max. black body temp.  $\approx 100^\circ C$

$\lambda_{max} = \frac{2900}{400} \approx 7.2 \mu$ . Only  $H_2O$  <sup>absorbs</sup> here. But it absorbs strongly (band centered on  $6 \mu$ ). ..., if no volcanic heating of Vermilion surface, diff. between observed + computed temps  $\Rightarrow H_2O$ .

Notes on  
Some  
~~Non-Mercurian~~ Extraterrestrial ~~Solar System~~ Objects  
of Possible Biological Interest

1. Mercury

Dollfus on atmos. pressure: Temp: of day + night sides. Libration, "twilight zone". Heat conduction to cool side if planet primarily iron? Temp for Poynting - Robertson particles not already vaporized by sun. Beigerstadffitch showed red, other dark side probably sept. Surface features: Antoniadi, seasonal changes? Polarization: Lyot.

2. Venus

Aerosols, pressure. CO<sub>2</sub> - Na - Vasyrev. Clouds. Temp: Radiometer, bolometer, rot. - vib., possibly high temps. refer to high atmos. Possibly cool poles. Period of rot.: Doppler, temp diff. between hot + cold hemispheres, cloud motions. Origin of CO<sub>2</sub>: Urey equilib., wind desert, universal ocean, Menzel + Whipple, CO<sub>2</sub> excess. Hough: H<sub>2</sub>O - H-C ratio. Clouds: C<sub>3</sub>O<sub>2</sub>, H-C's? Primitive history of Venus. Greenhouse effect for Venus. CO<sub>2</sub> abundance  $\rightarrow$  much H<sub>2</sub>O at one time (Urey). Variability of the 10μ CO<sub>2</sub> emission (Tammann, cf. Adel)  $\rightarrow$  clouds not emitting at 10μ ( $\therefore$  probably not C<sub>3</sub>O<sub>2</sub>).

Brown  $\mu = 3.3$  from <sup>Bo Dots</sup> occultation of 5 Arct. s mostly H + He.

Oblateness  $\rightarrow$  more centrally condensed than earth.  
Metallic hydrogen, rocky core

Intertins should be well above melting pt. of ice. Urey suggests water flows instead of lava flows. Kuiper it shows ice-like reflectivity of dinner plate satellite. No evap at these temps, so a little snow-frost would stay indefinitely.

$\text{CH}_3\text{CH}^+, \text{CH}_2, \text{CO}, \text{NH}, \text{NH}_2, \text{OH}, \text{OH}^+, \text{C}_2, \text{N}_2^+, \text{CN}$

Orb estimates  $10''$  w. total mass  $0.1 \text{ to } 0.01 \text{ M}_\odot$ .

Finite lifetime before disintegrating:  $\approx$  orbital revolution about sun after perturbed by Jupiter or stars. Origin of  $\text{C}_2, \text{C}_3$  from larger organic molecules. Comet-meteor connection. Bilds.

### 3. Jovian planets

Extensive atmospheres.  $\text{CH}_4$ ,  $\text{NH}_3$ ,  $\text{H}_2$ ,  $\text{He}$ ,  $\text{H}_2\text{O}$ .

Densities. Vertical structure: Wildt, de Marcus.

Bolometric temps. Non-thermal radio noise.

Grav. heating. Convection. Red spot: ~~flame~~ tem observed, interacts w. veil color, depression around it, Eötvös force, critical pt. Interpretation as cosmic Miller process. UV organic synthesis on Jovian planets. H-excess.  $\lambda 7500$  features.

If excess H, it is localized towards exterior; interior electric discharges effervesce, no photobios. Poss. of circulation into  $\text{NH}_3$  or  $\text{H}_2\text{O}$  seas. Chem. of liquid ammonia systems:  $\text{OH} \rightarrow \text{NH}_2$ . Dunham:  $\text{CH}_4 + \text{nob. gas}$ .

Best possibility here. Ubey suggests colors due to photochem. decom. products of  $\text{CH}_4$ ; Wildt Na salts reacting w.  $\text{Na} +$  nitrogen compds.

### 4. Satellites of Jovian planets

Temps, atmosphere, densities, albedos, surface markings.  $\text{H}_2\text{O}$  snow. Organic processes at low rates over long time intervals? Dark equatorial bands; if ~~Martin~~ features are due to vegetation as it poss. this too is vegetation? Frozen  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ ,  $\text{CH}_4$ , amines, etc. all have high albedos + are white. Important to obtain their reflection spectra. Vap. pressure  $\text{H}_2\text{O}$  on Ganymede:  $3 \times 10^{-10}$  atm. Orange color T.I.

### 5. Comets

Whipple icy model. Spectra. Masses. ST.

Chem. reactions: Dorn + Ubey. Orbits of long-period comets extending to interstellar distances. Here is best cosmobiological opportunity. 3-body orbits of comets around 2 stars. Hyperbolic orbits. Glintester-free spectral features. Organic syntheses

Rupert Wildt, "Photochemistry of Planetary Atmospheres," Ap. J. 86: 321, 1937

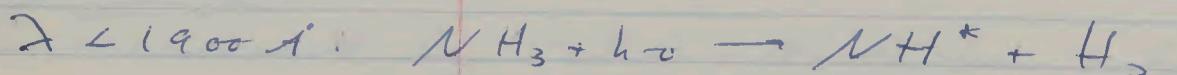
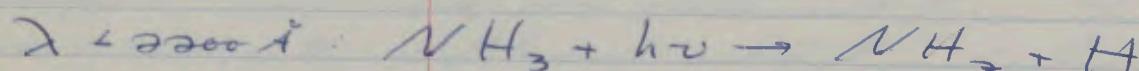
In an atmosphere containing very little  $O_2$ , say  $\sim 5 \text{ gm cm}^{-2}$ ,  $O_3$  largely formed near ground + might attack planetary surface. Possibly the case for Mars.

Low pressure bands of  $CH_+$  start at  $\lambda 1300$ , at high pressure extend to  $\lambda 1450$ . Sequence of increasing absorptivity at longer  $\lambda$ :  $CH_+$ ,  $C_2 H_6$ ,  $C_2 H_4$ ,  $C_2 H_2$ .  $NH_3$  absorption will prevent  $HC'$  photo-dissociation. Acetylene polymerizes in uv; reaction product is precipitated as a solid.

H atoms "are known to attack violently all hydrocarbons, methane excepted, + to cause hydrogenation, breaking of carbon chains, and, principally, dehydrogenation." + H atoms are formed by processes such as



Ammonia decomps. goes as



$NH_2^*$  are excited radicals showing strong fluorescence between  $\lambda 4000 + \lambda 6000$ , emitting the so-called  $\Delta$ -bands of  $NH_3$ .

"... the occurrence of methylamine in the atmospheres of [Jupiter + Saturn] should be envisaged. Traces of the radicals  $\text{CH}_3$  and  $\text{NH}_3$  will certainly recombine, and since in the range of temperatures with which we are concerned here the vapor tension of  $\text{CH}_3 \cdot \text{NH}_3$  is about one-tenth that of ammonia, there is little danger of condensation. Whether these traces can be detected by the spectroscope is a different question. It would be worth while to look for the rotation-oscillation bands of methylamine in the spectra of Jupiter + Saturn, although they may conceivably be difficult to disentangle from the heavy absorption of methane + ammonia."

C. H. Mayer, T. P. McCullough, + R. M. Sloanaker  
"Observations of Venus at 3.15 cm Wave  
Length," Ap. J. 127: 1, 1958.

"Whether the radiation measured at 3.15 cm is all of thermal origin + whether the radiation originates in the atmosphere of Venus or at the surface cannot be deduced from the present measurements without additional data." Measurements at 9.4 cm suggest that bulk of received radiation is thermal, but precision very low radiometric.

Measurements by Petit + Nicholson, + by Suntar give apparent black body temp of  $235^{\circ}$  to  $240^{\circ}\text{K}$ . This presumably is for top of cloud layer. Rot. temp of  $\text{CO}_2$  [Chamberlain + Kuijken, 1956] is  $285^{\circ}\text{K}$ . Max. surface temp estimated by Wilden (1940) at  $408^{\circ}\text{K}$ . Possible the 3.15 cm radiation comes from a heavily ionized atmospheric layer, but unlikely since electron densities

orders of mag. higher than in terrestrial atmosphere are required.

Deduced apparent black body temp.

near beginning of observing period:  $620^\circ \pm 110^\circ$  K.

near end " " "  $560^\circ \pm 73^\circ$  K.  
(i.e., at inferior conjunction  $\Rightarrow$  for dark side of Venus)

At 9.4 cm, one  $T \approx 430^\circ$  K.  $\pm 50\%$ , the other  $T \approx 740^\circ$  K.  $\pm 50\%$ . Avg. is  $580^\circ$  K. which compares favorably with 3.15 cm. measurements.

K.L. Franklin and B.F. Burke, "Radio Observations of Jupiter," A.J., 61: 177, 1950

22 Mc/s "A correlation between the presence of the Red Spot + occurrence of radio storms is mentioned with the caution that identification is uncertain + circumstantial." [A high degree of right-hand [radio convention] circular polarization in bursts; nearly 100% in some cases.]

J. D. Kraus, "Some observations of the impulsive radio signals from Jupiter," A.J. 61: 182, 1950.

Signals are bursts of short duration, suggestive of an electrical discharge phenomena [sic] similar to terrestrial lightning. Peak radiated radio power at the source of the order of 10 kilowatts per cps bandwidth.

Kraus, Nature 178: 159, 1950 claims period not Venus =  $22^{\text{h}} 17^{\text{m}}$ ; from interpretation as a beat frequency the 13 day periodicity of Venus noise.

G. P. Kuiper, "Infrared observations of planets + satellites," A. J. 62: 245, 1957

Polarization measures of Venus at 1 and  $2\mu$  rule out water droplets for clouds. Jupiter I + IV spectroscopically resemble sun + moon between  $1 + 2.5\mu$ , but III + especially II "are markedly different, in the sense that the spectrum beyond  $1.5\mu$  is reduced in intensity by a factor of 2-3. Explanation: snow. Visual albedo + color of II comparable w. snow, but III is darker. suggests "snow contaminated w. silicate dust."

T. D. Carr, "Radio frequency emission from the planet Jupiter," A. J. 64: 39, 1959

C. A. Shain (Anstr. J. Phys. 9: 61, 1956) showed correlation w. System II ( $9^h 55^m 40.6^\circ$ ) not but not w. System I ( $9^h 50^m 30^\circ$ ). Dallet (1957, unpublished) deduced noise sources on planet were rotating at const. period ~ 10 secs. less than System II. Carr et al. (Ap. J., 127: 279, 1958) found rot. period const. at  $9^h 55^m 28.8^\circ$ ; "System II".

Noise is entirely different from terrestrial radio static. More likely plasma oscillations in Jupiter's ionosphere. Dallet maintains oscillations are excited by shock waves arising from volcanic explosions in Jupiter's crust? else how explain the period?

Rupert Wildt "Note on the Surface Temperature of Venus," Ap. J. 91: 266, 1940

$\epsilon$ , emissivity of  $\text{CO}_2$  "While  $\epsilon$  increases with the thickness of the radiating layer, expressed in meter-atmospheres of  $\text{CO}_2$ , it is practically independent of the temperature  $T$  for layers thicker than about 0.10 m-atm," + has value  $\epsilon = 0.35 \pm 0.05$ .

For a slowly rotating black planet w. spherical albedo  $A$ ,

$$T = 392 \sqrt[4]{(1-A)/\alpha^2}$$

For Venus,  $A \approx 0.60$ , so  $T = 366^\circ\text{K}$ . Including effect of atmosphere, we have from energy balance

$$(1-\epsilon)T_s^4 + \epsilon T_A^4 = 366^4.$$

$\nearrow$   
radiation escaping between  $\text{CO}_2$  bands from the surface (temp  $T_s$ )

$\nwarrow$   
emission of atmosphere directly outward) can be ascribed to layer having effective temp  $T_A$ .

"For obvious physical reasons,  $T_A < T_s$ .  
 $\therefore T_s$  (max.) obtained by setting  $T_A = 0$ .  
 $\therefore T_s$  (max) =  $408^\circ\text{K} \pm 8^\circ\text{K}$ .

$\therefore$  surface temp. appears to be above the boiling pt. of water.

[But now know  $T_A$ ; have idea of period of rot.  $\therefore$  better  $T_s$ . Also, application to Mars?]

Dinsmore Alter "The Kogozhev Observations of Alphonsus," PASP, 71: 46, 1959.

Letter from Kogozhev: "The most prominent emission bands start at  $\lambda 4756$  & contain the strong Swan bands of the  $C_2$  molecule at  $\lambda\lambda 4735, 4713, + 4696$ . Also present are the Swan bands at  $\lambda 5105 + \lambda 5130$ . One sees clearly the group of bands due to  $C_3$  that occurs between  $\lambda 4100 + \lambda 3950$  in comet spectra." Alter sees in prints sent to him only the strongest features.

J. F. Gibson + R. J. McEwan "Observation of Venus at 8.6 mm wavelength," p. 50 of Paris Symposium on Radio Astronomy, R. N. Bracewell, ed., Stanford Cl. Press

Brightness Temp. for Venus of  $410^{\circ}\text{K.} \pm 40^{\circ}\text{K.}$ , i.e., between  $250 + 570^{\circ}\text{K.}$

## Venus As An Object of Possible Biological Interest

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### A. Introduction

The existence of living organisms on the earth's surface is strong evidence for the large-scale production of organic molecules at some time in the remote past. The most likely mechanism for such synthesis is the application of energy to a mixture of methane, ammonia, water vapor and hydrogen, the ~~gaseous~~ probable <sup>major</sup> constituents of the ~~prehistoric~~ early atmospheres of the terrestrial planets. Both electric discharges ~~and solar~~ (Teller, 195~~4~~) and ~~a~~ <sup>energy source</sup> ultraviolet radiation (Frost, 195~~4~~) are known to be effective; the latter was probably dominant in early times because ~~of~~ much more energy is available in solar ultraviolet

an extensive cloud layer obscures the  
surface features; as a consequence

radiation than in common forms of electric discharge, for example, lightning. Molecules produced in the high atmosphere would have diffused to lower depths where ~~exposure~~ of ultraviolet photodissociation was ~~less~~ probable. In general the diffusion times will depend ~~most~~ critically on the planetary gravitational field. Since the ~~mass of Venus~~ is of the ~~same~~ Cytherean <sup>surface</sup> gravity ~~is~~ ~~is~~ is 0.86 ~~of~~ the terrestrial surface gravity, and since the primitive atmospheres of Venus and earth <sup>must have been</sup> ~~are~~ very similar, it seems likely that comparable organic syntheses occurred on Venus as on earth.

Although Venus is the nearest planet to the earth, we know ~~but~~ nothing directly about the possible presence ~~of~~ and evolution of organic matter on that planet. In this paper we discuss <sup>what is known</sup> ~~the pertinent details~~

The existence of a Cytherean atmosphere is shown by two phenomena, the polarization of the sunlight reflected from Venus, and the prolongation of the cusps of Venus' crescent near inferior conjunction.

~~but~~ and what is speculated about the  
~~of the past~~ Cytherean physical environment,  
and ~~that~~ is speculated ~~for~~ <sup>to</sup> the past, in  
order to assess the possible biological  
~~importance of the planet~~ interest of Venus  
for the biologist.

### B. Atmosphere

Merely those ~~parts~~ portions of the Cytherean  
which are above the cloud layer are  
atmosphere accessible to spectroscopic inves-  
tigation are those above the cloud layer.  
Since ~~of~~ ~~the~~ ~~cloud~~ ~~no~~ ~~information~~ the cloud  
layer may be tens of kilometers above  
the surface, the only information directly  
available pertains to the high atmosphere  
of Venus. If only <sup>the</sup> ~~the~~ portions of the  
terrestrial ~~Earth's~~ atmosphere above, say, 40 km. were  
visible from the vicinity of Venus, it is  
doubtful whether CO<sub>2</sub>, H<sub>2</sub>O, <sup>O<sub>3</sub></sup> or N<sub>2</sub> would  
be discovered on earth. This limitation must  
be born in mind in attempting to

W. S. Adams + T. Dunham (1932) Pub. Astro. Soc. Pac., 44: 243.  
T. Dunham (1952) A.E.P., chap. 11.

(1934)

A. Adel + V.M. Slipher, Phys Rev, 46: 240,  
G. Herzberg (1932) A.E.P., chap. #13.

Describe the composition of the ~~Cytherean~~ atmosphere at the surface of Venus.

### 1. ~~CO<sub>2</sub>~~ Carbon Dioxide

In an attempt to discover water on Venus, Adams and Dunham (1932) found three features ~~too~~ absorption bands in the photographic infrared which were subsequently identified as intercombination bands of the carbon dioxide molecule (v. Dunham, 1952).

Long path-length laboratory comparison spectra (Adel + Slipher, 1934; Herzberg, 1952) indicate the amount of CO<sub>2</sub> above the Cytherean cloud layer is of the order of 1 km-atm or about ~~at~~  $2 \times 10^5$  dynes/cm<sup>2</sup> on Venus. In order to give some idea of the surface partial pressure of CO<sub>2</sub>, we assume an atmosphere in adiabatic equilibrium, ~~with~~ having a pressure  $p = 2 \times 10^5$  dynes/cm<sup>2</sup> at a level <sup>which is</sup> 20 km.

N.A. Kozyrev (1951) Doklady Akad. Nauk USSR 12: 169.

high and characterized by a temperature  $T = 250^{\circ}\text{K}$ . (v. below, § D). The resulting pressure is ~~approximately~~.

$$P_0 = \dots \quad (1)$$

$=$  dyes  $\text{cm}^{-2}$  at the surface.

In equation (1),

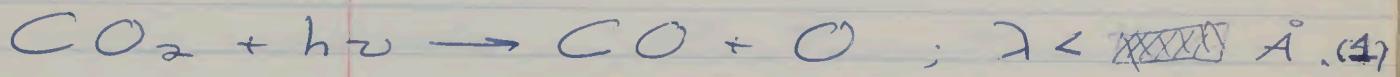
## 2. Carbon monoxide and molecular nitrogen

Kozyrev (1954) reports observing several features in the aurora and night sky of Venus corresponding in wavelength to known emission bands of  $\text{N}_2$ ,  $\text{N}_2^+$ , and  $\text{CO}^+$ . In particular he reports the  $\lambda 3914 \text{ } \text{N}_2^+$  band which is prominent in the twilight airglow. terrestrial aurora and sight sky.

G. Newkirk (1959) J. Plan. Space Sci. 1:

Unsuccessful searches for CO absorption spectra by Kuiper (1952), place the amount of CO above the cloud layer at  $< 100 \text{ cm-atm}$ .

From general abundance considerations and terrestrial analogy,  $N_2$  — which has no permitted absorption spectrum in the presently accessible ~~wave~~ wave-length regions — should be expected on Venus. Similarly, in an extensive  $CO_2$  atmosphere, CO should be expected from the reaction



Nevertheless, Newkirk (1959), using ~~superior~~ ~~small~~ ~~sup~~ photoelectric equipment, was unable to confirm Kogyyev's observations. Newkirk found no evidence of many of Kogyyev's strongest features, including the  $\lambda 3917 N_2^+$  band; on the other hand, he found strong emission at <sup>neighboring</sup> wave-lengths not reported by Kogyyev, and corresponding to no known molecular emission features. At the present writing one must conclude

[Check this: Monroe (+ Whipple) get ~0.2 mm for  $H_2O$ ; also  $O_2$  supposed to be good to  $10^{-3}$  terrestrial ~1 meter.]

there is no direct evidence for  $N_2$  and CO on Venus.

### 3. Water vapor and molecular oxygen

Cursory examination of high-dispersion spectra of Venus indicates the abundances of  $O_2$  and  $H_2O$  do not approach that of  $CO_2$ . Because of the absorption by  $O_2$  and  $H_2O$  ~~molecules~~ in the terrestrial atmosphere, identification of small amounts of these molecules in the Cytherean atmosphere is rendered difficult. When the <sup>relative</sup> radial velocity of Venus and the earth is greatest, ~~approx~~ Doppler shift of the order of  $0.5 \text{ \AA}$  can be expected.

Observations made at such times permit upper limits to be placed on the amounts of these molecules above the cloud layer.

~~With O<sub>2</sub>~~ There must be ~~O<sub>2</sub>~~ <sup>40</sup> ~~and H<sub>2</sub>O~~ <sup>O<sub>2</sub></sup>; ~~H<sub>2</sub>O~~ <sup>H<sub>2</sub>O</sup> (cf. Dunham, 1952).

<sup>P</sup>  
Kuiper, A.E.P., Chap. 12, O'Ch. Press, 1952

These limits are not very restrictive; they correspond approximately to the terrestrial atmosphere <sup>above</sup> about ~~at~~ about 10 km. altitude. It is in our present state of ignorance clear that, in biologically significant quantities of oxygen and water vapor may exist beneath the cloud layer. For comparison it may be recalled that the total amount of water vapor in the Martian atmosphere and polar caps is less than a few mm<sup>2</sup>-atm. ~~Others~~ ~~et al.~~ Observations of Venus from an extraterrestrial observatory are required to further refine these abundance limits.

#### 4. Other ~~substances~~ molecules

Kniper (1952) places the following Cytherean abundance upper limits on the following molecules:  $N_2O < 1$  meter-atm;  $NH_3 < 4$  cm-atm;  $CH_4 < 20$  cm-atm;  $C_2H_4 < 3$  cm-atm; and  $C_2H_6 < 1$  cm-atm. The hydrocarbon abundances will be of interest to us below.

H. N. Russell, Op. J. 2:287, 1899.

Atmospheric composition  
5. Total atmospheric pressure above the cloud layer

The prolongation of the cusps of the Cytherean crescent near inferior conjunction, and the occasional coalescence of the cusps into a ring, were demonstrated by Russell (1891) to be due to scattering by particles above the cloud layer, and not due to refraction. Russell calculated that the height of the Cytherean atmosphere which can be seen by scattered sunlight during terrestrial twilight is about 15 km, while that responsible for cusp prolongation is about 12 km.

On the other hand, comparison of the degree of polarization of sunlight reflected from Venus in the green, with that reflected in the red, indicates an atmospheric pressure above the cloud layer of about 90 millibars (Dollfus, 1957).

is between 0.79 and 1.2 km.

For a layer of thickness, the barometric formula, is approximately valid. Taking

$$p = p_0 e^{-h/H}$$

is approximately valid, where  $p$  is the pressure at the top of the scattering layer,  $p_0$  is the pressure at the top of the cloud layer,  $h$  is the height of the scattering layer, and  $H$  ~~is the scale height~~  $= \frac{kT}{mg}$  is the scale height of the atmosphere at this altitude. Setting  $H = 15$  km.,  $T = 285^\circ K.$  (v. below, § D4), and  $g = 860 \text{ cm } \cancel{\text{sec}}^{-2}$ , we find for the <sup>average</sup> molecular weight of the Cytherean atmosphere immediately above the cloud layer

$$\bar{\mu} = 20.$$

(21)

Since  $\bar{\mu}_{CO_2} = 44$ , the calculation suggest the presence of molecules of lower molecular weight, probably ~~the~~ nitrogen. For a density for an atmosphere in which

CO<sub>2</sub> and N<sub>2</sub> are predominant, the abundance ratio can be obtained from

$$\frac{N_{CO_2} \times 44 + N_{N_2} \times 28}{N_{CO_2} + N_{N_2}} = 20,$$

balance,

The principal uncertainty in this calculation is of course the assignment of the apparent height of the scattering layer to the scale height of the atmosphere. However since the scale height of the suspended particles is unlikely to be greater than the scale height of the supporting atmosphere, it may be looked upon as a representation of the atmosphere. This consideration would only serve to further decrease  $\tau$ . However it may be that Prof. Russell's value of 15 km. is ~~applying~~ for the height of the scattering layer corresponds to ~~more than~~ ~~more~~ height a reduction in atmosphere.

density by a factor larger than  $e$ , <sup>and</sup>  
~~which~~ <sup>then</sup> it would be ~~long~~ greater.

In any case, the computation suggests  
the presence of molecules of smaller lower  
molecular weight than  $\text{CO}_2$ , probably  
 $\text{N}_2$ .

A similar calculation can be made  
for those particles in the large layer

immediately above the cloud layer which are  
responsible for cumo prolongation. Taking  
the two values  $H_1 = 0.79 \text{ km}$ ,  $H_2 = 1.2 \text{ km}$ ,  
now, with the other parameters  
as before, we derive

$$\frac{\mu_1}{\mu_2} \approx 350 \quad 380 > \bar{\mu} > 250 \quad (3).$$

This result is subject to the same  
uncertainties as the preceding one;  
nevertheless its order of magnitude suggests  
the presence of molecules of high molecular  
weight in the Cogherian large layer.  
It is reasonable to expect some

W.H. Pickering, P.A.S.P.   37:12, 1925  
E.J. Opik, I.A.J.   #37, 1950

connection between these molecules and those in the immediately underlying cloud layer.

### C. Cloud Layer

#### 1. Visual ~~studies~~ and photographic studies

Visual observations of Venus generally show very little detail owing uniformly to the high albedo of the cloud layer.

The ~~general~~ color of Venus is a somewhat pale <sup>yellowish</sup> white as is evident during daylight telescopic observations when comparison can be made with terrestrial clouds.

(Pickering, 1925). The yellowness of Venus is also observed photometrically (e.g., Opik, 1950). Under the best seeing conditions faint dark markings can be perceived on the illuminated part of the Cylindrical disk. A broad band of shade adjoining the

F. E. Ross, Ap. J., 68: 57, 1928

The difficulties of visual observation of Venus are illustrated by the fact that E. E. Barnard, in over a decade of regular observing of Venus, was able to see distinct markings only once. On that occasion shading was evident parallel to the terminator but not perpendicular to it (Barnard, 1897)

E. E. Barnard, Ap. J., 5: 300, 1897

A. Dollfus, L'Astronomie, 65: 413, 1955

A. Danjon, 1943

In <sup>some</sup> Dollfus's drawings there is a tendency for the dark markings to radiate from the sub-solar point.

terminator ~~app~~ sometimes appears brown (Ross, 1928). Other markings, both bright and dark, can ~~sometimes~~ be observed; occasionally dark bands are seen. A feature of interest is the occasionally dark bands are seen extending perpendicularly from the terminators on to the disk.<sup>41</sup> Some features, show a degree of permanence in position while varying ~~shifting~~ ~~variations~~ in form and intensity, ~~remain~~, show no apparent motion over periods of weeks. Danjon (1943) and Dollfus (1955) have interpreted this phenomenon as ~~constucted~~ pliomospheric from their visual observations; they show diffuse dark markings in relatively constant position. Danjon and Dollfus interpret the constancy of position of ~~the~~ <sup>those</sup> dark markings as surface features seen through stable gaps in the cloud layer. The apparent constancy in position

of the dark markings have suggested to the French astronomers that the period of rotation of Venus is equal to its period of revolution, 225 days.

### 2. Photographic studies

The photographic detail visible on Venus varies inversely as the wavelength; markings are most evident in the near ultraviolet, and least evident in the photographic infrared. The classic ultraviolet photographs of Venus are those of Ross (1928) taken with the 60-inch and 100-inch Mt. Wilson reflectors. His sequence of fifty plates taken over a two-month period shows a set of extremely variable bright and dark areas, sometimes stretching band-like ~~free~~ perpendicular from the terminator on to the disc. Generally there is a dark shading adjacent to the terminator

This, in turn, implies an appreciable temperature difference between the Cytherean equator and the Cytherean poles. It would be of great interest to determine the composition of the polar ice.

as in visual observations. Perhaps the most striking feature of Ross' photographs are the departures of the crescent from a symmetric form. Especially where there are bright ~~ridges~~ <sup>features</sup> along the planetary limb protrudes markedly. On the other hand, when there are nearby dark features, the terminator takes on a serrated appearance. The bright protruding features are prominent near the apparent poles, especially the southern; they were also ~~observed~~ <sup>detected</sup> visually by early observers such as Schröter and Trouvelot who explained them as enormous mountains 60 or more kilometers high. Ross proposed the more likely explanation that ~~this~~ <sup>the protrusions</sup> are atmospheric haze surrounding the planetary poles, as is ~~the case~~ <sup>exists</sup> on Mars. The rapid day-to-day changes in the form, intensity and position

G. P. Knipper, Ap. D., 120: 603, 1954  
R. S. Richardson, P.A.S.P., 67: 304, 1955

of the ultraviolet markings led Ross to question the reliability of visual observations claiming to ~~do~~ follow the same feature for many weeks. Consequently the <sup>proposed equality</sup> ~~identification~~ of the Cytherean day and the Cytherean year ~~is~~ is subject to the same objection. The <sup>rapid</sup> variation in the markings on Venus indicates a highly convective atmosphere in which adiabatic equilibrium should obtain.

Ultraviolet photographs taken by Kuiper (1954) and <sup>by</sup> Richardson (1955) give evidence for the presence of three bright and three dark bands "roughly" perpendicular to the position of the terminator and extending across the entire visible hemisphere of Venus. Suggestions of these features can also be seen in Ross' photographs. The inclination of the bands to the plane of the Cytherean orbit is estimated by

V. M. Sipher, Lowell Obs. Bull., Nos. 3 + 4, 1903

Kniper at  $32^{\circ}$ , and by Richardson at  $14^{\circ}$ . The difference between these values emphasizes the observational difficulties.

Ross attributed the presence of the band structures to atmospheric circulation, as is ~~for~~ the case for the Jovian planets. If the explanation is correct then the speed of equatorial rotation must exceed that of random atmospheric winds (v. e.g., Opik, 1956), giving a period of rotation of a few weeks at most. The minimum value for the period of rotation is obtained from the absence of a rotational Doppler shift at the planetary limb (Slipher, 1903). Thus the period of rotation is probably bracketed between five and thirty days. ~~Opik (1956) thus suggested~~

3. Polariscopic studies potentially method a powerful tool for the ~~analysis~~ of the Cytherean cloud layer is the analysis of the polarization of sunlight reflected from Venus to earth. If  $I_p$  and  $I_{\perp}$  are, respectively, the received intensities parallel and perpendicular to the plane of the plane defined by the sun, earth, and Venus, then the degree of polarization is

$$P = \frac{I_p - I_{\perp}}{I_p + I_{\perp}}$$

If  $I_p = I_{\perp}$ , the light is unpolarized if  $I_p > I_{\perp}$ ,  $P > 0$ , while if  $I_p < I_{\perp}$ ,  $P < 0$ . The degree of polarization is measured as a function of the phase angle  $\alpha$ ; i.e., the angle sun-Venus-earth, which varies from 0 to  $180^\circ$ . For the integrated light from the visible segment observationally accessible part of the

B. Igot, Ann. Obs. Nendow, 1929.

5 : 66

illuminated Colhanean hemisphere,  $p(\alpha)$  has the following general form (Lyot, 1929):  
 $p$  is negative for  $0^\circ < \alpha < 8^\circ$ , reaching a <sup>relative minimum</sup>  
 $p(6^\circ) = -0.002$ ;  $p$  is positive for  $8^\circ < \alpha < 23^\circ$  reaching a relative maximum  $p(18^\circ) \approx +0.015$ ;  
 $p$  is negative for  $23^\circ < \alpha < 145^\circ$ , reaching a relative minimum  $p(120^\circ) = -0.027$ ; and  
 $p$  is positive for  $145^\circ < \alpha < 180^\circ$ , reaching a relative maximum  $p(155^\circ) \approx +0.020$ .

Lyot then attempted to duplicate this run of  $p$  vs.  $\alpha$  with various substances in the laboratory. He found that only transparent particles would give relative maxima and minima of the order of a few per cent, and that  $p(\alpha)$  depended strongly on the index of refraction,  $n$ , and the radius,  $r$ , of the ~~spherical~~ particles. The amplitude of the curve, but not its slope, depended on the

density of particles; i.e., whether light scattering was single or multiple.

In order to approach the Venus polarization curve, Lyot was obliged to experiment with micron-sized ~~particles~~ <sup>droplets</sup> in colloidal suspension. The best fit to the maxima, minima, and zeroes of the Cytherean  $p(\lambda)$  was obtained for a ~~sus-~~ <sup>colloidal</sup> suspension of bromonaphthalene ( $n = 1.33$ ,  $r = 2.3 \mu$ ). However the bromonaphthalene  $p$  was not negative for  $0^\circ < \lambda < 8^\circ$ . Furthermore, no amount of scaling could. However, even then the fit was poor. Although bromonaphthalene had the three major maxima and minimum ~~at~~ very roughly <sup>approximately</sup> the Cytherean  $\lambda$ ,  $p$  was positive for  $0^\circ < \lambda < 8^\circ$ . Furthermore, no amount of scaling could match amplitudes; in the final

(It is to be emphasized that in Lyot's (1929) laboratory comparisons for the polarization curves of the Moon, Mars, and Mercury near-perfect fits were obtained.)

amplitude assignment,  $p(8^\circ) \approx 0.070$  for bromonaphthalene, compared with  $p(8^\circ) \approx 0.000$  for Venus. Nevertheless, because of his great difficulty in finding any other substance ~~even~~ approximating the Cytherean  $p(\alpha)$  <sup>even</sup> as well as bromonaphthalene, Lyot concluded that the particles responsible for the polarization of the light reflected from Venus were characterized by  $r = 2.2\mu$ ,  $n = 1.33$ . Since the index of refraction of water droplets is also 1.33, he thought water was the specific substance involved. Water itself had not been tried, because it was found impossible to prepare water droplets with so small a radius; a spray of such droplets is unstable and immediately condenses or precipitates.

A. Dollfus, Suppl. Ann. d'Ap., no. 4, 1957

Dollfus (1957) has measured the variation of polarization over the disk of Venus, both in the green and in the red. The general pattern is the same at both wavelengths, but the <sup>absolute value of the</sup> degree of polarization is greater in the red. Regions of high (negative) polarization are localized in the apparent polar ~~regions~~ <sup>south</sup> & ~~north~~ consistently greater in polar regions than in the others. Identification with the bright visual + photographic features in the same regions is tempting. However, there appears to be no consistent difference in  $p$  between the two poles, while the bright areas near the apparent south pole ~~are~~ usually more brilliant than those near the apparent north pole. Indeed comparison of visual and polarimetric observations made on the same day show no ~~any~~ clear correlation, and

The difference between the apparent carbon dioxide pressure (~~170~~ mb) and the <sup>apparent</sup> polarimetric pressure (90 mb) supports this possibility.

G. P. Kuiper. In The Threshold of Space, M. Zelikoff, ed., p. 78,  
Pergamon Press, 1957.

~~it is not~~ <sup>likely</sup> possible  
it is not ~~impossible~~ that the particles  
responsible for the polarization ~~are~~  
~~at a different level from the particles~~ <sup>that of</sup>  
~~in~~ <sup>the visual and photographic cloud</sup>  
~~layers~~ <sup>edges</sup> are different from those responsible  
for the visual and photographic cloud layers.

Kuiper (1957) has performed some  
measurements of the Cytherean polarization  
wavelength  
in the 2 micron region. Comparison with  
theoretical polarization curves for  $n=1.33$   
and  $r$  between  $3\mu$  and  $4\mu$ , shows appreciable  
discrepancies. Kuiper concludes  
~~discrepancies~~; the conclusion is that ~~whatever~~  
else the substance responsible for the polarization  
on Venus is not water.

Since, as we have mentioned, the particles responsible for the polarization may be different from those responsible for the cloud layer, it is interesting that

#### 4. Nature of the cloud layer

##### a. Water

Despite the differences between the polarization curves of Venus and of water droplets, some authors continue to quote the polariscope observations as evidence for water on Venus. ~~But these may still be some uncertainty in the interpretation of the polarization data. It is not clear that there exists~~ other evidence against the presence of water in or above the cloud layer, as discussed long ago Öpik (1950) and Slipher (1957):

(i) No water vapor is observed spectroscopically.

(ii) A fog of water particles with mean radius  $\approx 2 \mu$  is unstable, as Tyndall observed in the laboratory.

(iii) The clouds of water droplets should be white or bluish-white.

The absence of spectroscopically-detectable amounts of water vapor above the cloud layer is not evidence against water clouds. Menzel and Whipple (1955) calculate that in adiabatic equilibrium the amount of saturated water vapor above the ~~cloud layer~~ a Cylindrical water cloud layer would be within the spectroscopic tolerances.

Now despite the foregoing evidence, ~~the~~ it ~~possibility~~ should not be forgotten that the admixture of other substances may change the properties of water clouds. Menzel and Whipple (1955) have suggested that Cylindrical water is carbonated because of the high carbon dioxide partial pressure. The polarization curve, droplet stability, and albedo of carbonated water clouds are unknown.

Especially considering the high cosmic abundance of water, it seems that the presence of a dirty water cloud layer on Venus cannot be definitely excluded at present.

The Cytherean cloud layer is yellowish.

(\*\*) The albedo of Venus is higher than the expected albedo of clouds composed of very small water droplets.

We must conclude <sup>only</sup> that the Venus polarization is probably produced by small, transparent droplets. The present variety of laboratory polarimetric comparisons is not yet sufficiently advanced ~~yet~~ to determine the refractive index, radius, or composition of the particles ~~possibly~~ polarizing the light on Venus.

#### b. ~~Other~~ Inorganic salts

A suggestion frequently encountered in the literature is that the clouds contain inorganic salts such as  $\text{NaCl}$  or  $\text{NH}_4\text{Cl}$  which impart <sup>the</sup> yellow coloration

to the cloud layer. The powder is supposed to be produced by wind erosion at the surface of Venus and transported to the high atmosphere by convection. This concept is usually associated with the windswept desert picture of the Cytherean surface (v. below).

Although there is nothing untenable in the presence of small amounts of salts in the high atmosphere of Venus, it is certainly impossible that the clouds should be composed primarily of salts. That the salts are <sup>also</sup> an impurity in water clouds can be excluded because the salts, acting as condensation nuclei, would only increase the already great motility of micro-size water droplets. In addition the polarization curve of such substances in ~~now~~ <sup>general does not</sup> resemble the

(However van de Hulst [1952] points out  
transparent spherical  
that "gray" particles - refractive index  
1.50 and radius between 5 and 10 microns  
- gives a zero in the polarization curve  
near  $\lambda = 73^\circ$ , as exists in the Cytherean  
polarization curve.)

H.C. van de Hulst, Q.E.P., chap. 3, 1952.

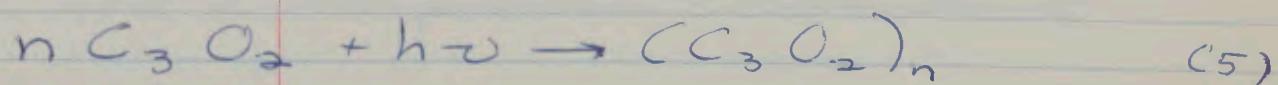
Venus polarization curve, which is, as we have mentioned, most nearly approached by transparent droplets or particles.

### c. Carbon suboxide

Droth and Hartech (v. Kuijper, 1957) have suggested carbon suboxide,  $C_3O_2$ , as the substance responsible for the cloud layer. The proposed mechanism of synthesis is photoproductio from carbon dioxide and carbon monoxide by ultraviolet light:



the CO arising from reaction (1) or according to Kuijper (1957), from volcanic exhalations. Carbon suboxide polymerizes when irradiated,



forming a slightly yellowish fine powder; although ~~a denial of the~~ doubts us to the reality

R. S. Newburn, In Exploration of the Moon,  
the Planets, and Interplanetary Space, A.R. Hibbs,  
ed., p. 68, Report 30-1, JPL, CalTech

The proposal identifies the need  
of invoking only known substances known  
~~likely~~<sup>(CO<sub>2</sub>)</sup> to exist or expected for sound  
physical reasons [CC, reaction (1)]

have been expressed  
~~existences~~ of reaction (5) can be found  
(Newburn, 1959). Another advantage of this  
hypothesis was considered to be the  
temperature-independence of reactions  
(4) and (5); At the time of the writing  
of Kniper's paper, Dollfus' observations  
<sup>(1957)</sup> were ~~were~~ not readily available, and it  
was believed that the degree of polariza-  
tion was <sup>very nearly</sup> constant over the disk  
of Venus. We now know (Dollfus,  
1957) that  $p$  may vary by a factor  
of two between the apparent poles and  
the apparent equator, an effect  
most readily explained by a temper-  
ature variation with Cothorean lat-  
itude and a temperature-dependent  
cloud layer.

However, there are other, more direct,  
objection which can be raised against

There are two band systems with centers at  $10.41\mu$   
and  $9.40\mu$  (Barker + Adel, 1933) attributed to  
the  $v_3 \rightarrow (v_1, 2v_2)$  transition. The half-widths  
are between  $\sim 930\text{ cm}^{-1}$  and  $\sim 980\text{ cm}^{-1}$  for the  $10.41\mu$  feature  
and  $\sim 1040\text{ cm}^{-1}$  and  $\sim 1090\text{ cm}^{-1}$  for the  $9.40\mu$  feature.

C. O. Lampland, Ap. J. 93: 401, 1941.

E. F. Barker + A. Adel, Phys. Rev. 47: 185, 1933.

a  $C_3 O_2$  cloud layer:

(i) It is evident from reaction (4) that a molecule of oxygen is produced for each molecule of carbon suboxide.

Yet no oxygen is observed above the cloud layer.

(ii) Carbon suboxide polymers are not transparent droplets, and therefore should not be expected to give a polarization curve resembling that for Venus.

(iii) Carbon dioxide emission from Venus in the  $10\mu$  region is transmitted through the terrestrial atmosphere. Tamm-Land (1941) found the emission to be extremely variable, changing from over 60% of the Cytherium black body radiation to barely

G. Hengberg, Infrared + Raman Spectra of Polyatomic Molecules, van  
~~O Atoms, Ann. Phys.~~, Chap. 10, 1952. Nostlund, 1945, p. 305

However, the only bands of  $C_3O_2$  in this region with comparable strength to the  $CO_2$  features are at ~~9.40  $\mu$~~ , 9.77  $\mu$  and 11.00  $\mu$ .

(cf. Hengberg, 1945). The <sup>center of the</sup> stronger feature at 11.00  $\mu$  ( $909 \text{ cm}^{-1}$ ) is seen to lie ~~well~~ well outside the half-width of the 10.41  $\mu$   $CO_2$  band, while the <sup>center of the</sup> weaker feature at 9.77  $\mu$  ( $1024 \text{ cm}^{-1}$ ) is ~~well~~ outside the half-width of the 9.40  $\mu$   $CO_2$  band. The overlap between  $CO_2$  and  $C_3O_2$  seems to be ~~too small for~~ ~~too~~ too small for

detectable amounts. Since the quantity of  $\text{CO}_2$  abundance and emissivity of  $\text{CO}_2$  cannot be expected to vary by such amounts, the variability must be due to the occasional interposition of material which does not emit in the ~~between~~ <sup>which absorbs at 9.40 $\mu$  and 10.41 $\mu$</sup>  between the bulk of the Cyltherian carbon dioxide and the earth (~~at 6,7900~~).  
However,  
~~Since carbon suboxide disappears,~~  
~~for example, at 10 $\mu$  it is reduced~~  
~~to carbon dioxide, it is evident that~~  
~~it is in the 10 micron region displaying the~~  
~~characteristic CO<sub>2</sub> emission. Therefore carbon~~  
~~suboxide is ~~not~~ the material which~~  
~~obscures the 10 $\mu$  emission.~~

(iv) The albedo of Venus is much higher than laboratory samples of

Thompson and  
331, 1936.

Hawley, Proc. Roy. Soc. A, 157:

carbon suboxide.

These considerations make it appear unlikely that  $C_3O_2$  is the primary constituent of the cloud layer of Venus. However, some  $(C_3O_2)_n$  must be formed and it is possible that the yellow tint of the clouds arises from this source. More definitive checks on carbon suboxide would be desired. Regrettably, there are no published polarization curves for  $C_3O_2$  at any wavelength. A specific (IV) Carbon suboxide ~~like~~ vapor has a fairly strong absorption band system extending shortwards of 73350 (Thompson and Healy, 1936). No prominent Cytherean features have ever been identified in this spectral region.

search for  $C_3O_2$  vapor <sup>on Venus</sup> at  $\lambda \sim 3350\text{ \AA}$ ) would also be desirable; as would the study of other carbon-oxygen compounds possibly formed in the Cytherean atmosphere, such as ~~the~~ ~~organic~~ ~~molecules~~  $C_5O_2$ .

d. <sup>General considerations</sup> Other possibilities

We have seen that the polarization and the cloud markings ~~are from~~ be unrelated and may have dissimilar origins. different sources, but that water, inorganic salts, and carbon suboxide are unlikely to be the source of salts, and that the variation of polarization and cloud markings across the disk of Venus suggests some temperature-dependence in their ~~origins~~; either a temperature-dependent rate of production, or a temperature-dependent rate of presentation to view. The former possibility is somewhat un-

In our discussion of the prolongation of the clouds, we found some evidence for molecular particles of mean molecular weight equal to several hundred just above the cloud layer. Now a photochemical induced polymerization process might be expected to give something rather similar; monomers produced in the high Cytherean atmosphere, and polymerization at lower, denser levels. Molecules of  $M \approx 300$  (trimers, tetramers?) of ~~mean~~ molecular weight equal to a few hundred have molecular diffusion times to lower levels in the atmosphere of Venus of less than a day. take less than a day to diffuse to low levels in the atmosphere of Venus. In this view, the long-chain polymers would be localized in the cloud layer, and below, while the short-chain polymers and monomers would have an exponential density

C.G. Rossby, 1952, A.E.P., chapt 2.

distribution above the cloud layer.

If the precursors of the polymer all exist abundantly above the cloud layer, the photoproductive process would be temperature-independent. But if essential precursors ~~that~~ have only low abundance above the cloud layer, and ~~that~~ have to be supplied by convection from below, the temperature-dependence of such a process ~~can~~ <sup>can</sup> be understood. Polymerization will be most efficient where vertical convective mass-transport is also most efficient. Since the existence of a great circumpolar convective vortex is to be expected on a rotating planet, and is known for the earth, the localization of high negative polarization and extensive bright cloud systems near the apparent poles of Venus is very interesting.  
(Rossby, 1952)

S. S. Miller, 1955

W. Groth, 1959  
P. H. Abelson, 1950

It suggests that the substances responsible for the polarization and for the cloud layer come — either directly or themselves or their precursors — from lower altitudes.

In recent years a series of experiments have been performed on the application of energy to various atmospheric constituents, some of which are possible constituents of the atmosphere of Venus. The original experiments of Miller (1955), using a corona discharge in a mixture of  $\text{CH}_4$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ , and  $\text{H}_2$ , have been amplified and extended by Groth (1959) using ultraviolet light, and by Abelson (1956) and others on combinations of  $\text{CH}_4$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ ,  $\text{H}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{N}_2$  and  $\text{O}_2$ . As long as molecules containing hydrogen, carbon, nitrogen and oxygen were available

S. S. Miller, Ann. N.Y. Acad., 1957

S. L. Miller, private communication, 1959.

and the conditions were not oxidizing, a variety of organic molecules were produced. Upon solution in liquid water, amino acids were synthesized, but the large number of gaseous intermediaries existing before solution in water occurred remain largely unknown. Miller, who has made the most extensive analysis of products to date, has identified only 15% of the end-products (Miller, 1957); intermediaries are largely inferred only from theoretical considerations.

There appears here to be a wide variety of substances of potential relevance for the problem of the Cthulhu cloud layer. A material of possibly particular interest is a fine yellowish-brown organic polymer produced ~~by lightning~~ <sup>in high yield out of water solution</sup> under a number of different conditions (Miller, 1959),

and which has not been further identified to date. The interest in this polymer is heightened, of course, by the <sup>visual and</sup> photometric yellow color of the Venus, and the brownish tint to the <sup>dark</sup> shadings near the terminator. Experiments on the irradiation of  $\text{CO}_2$ ,  $\text{N}_2$ , and some <sup>some to</sup> hydrogen atoms, such as  $\text{H}_2$ ,  $\text{H}_2\text{O}$ , or hydrocarbons (see below) are clearly indicated followed by spectrographic and polarimetric analysis of the products, is clearly indicated.

Many of the products of similar experiments, already mentioned, give transparent liquid droplets at the temperatures of Venus, and have at least an a priori possibility of resembling the Cytherean polarization curve.

A <sup>possible</sup> additional source of material for the cloud layer is hydrocarbons and other organic molecules possibly existing

at the surface of Venus. This possibility is discussed in § E 2 below.

## D. Temperatures

### 1. Thermocouple measurements

In summary, any molecule or combination of molecules proposed to explain the Venus cloud and polarization data should have the following ~~similar~~ properties:

- (i) ~~Fit~~ the Coddington  $p(\lambda)$  curve in both the visible and the infrared
- (ii) ~~Fit~~ a color index  $\approx 0.35$  magnitudes redder than the sun (cf. Opis, 1956), i.e., ~~green~~ yellow coloration
- (iii) an albedo  $\approx 0.7$  (Kuijper, 1957)
- (iv) droplet stability at the size required to explain the polarization
- (v) absorption at  $9.40\mu$  and  $10.41\mu$
- (vi) no strong visible absorption features at the required concentrations either for the molecules, their precursors, their reaction products, or subsidiary products made in their synthesis, or the molecules besides those features already identified in Venus spectrum.

E. Petit + S. B. Nicholson, 1955

At the present time no organization has been

#### D. Temperatures

##### 1. Bolometric measurements

Thermocouples may be used in  
with large telescopes to determine the total  
radiant  
energy received from Venus through the  
terrestrial atmosphere. To derive plane-  
tary temperatures from such data, consid-  
erable correction must be made for the  
transmission properties of the thermocouple  
cell windows and of the terrestrial at-  
mosphere. Such measurements and corrections  
were performed by Petit and Nicholson  
(1955) who found a mean temperature <sup>of 235°K.</sup> for  
the daylit side of Venus from 11 observa-  
tions; and of 240°K. for the night side  
from 17 observations. Petit + Nicholson  
considered the difference between the two  
values to have no statistical signifi-

Sinton (1953) finds bolometric temperatures  
within a few degrees of the Petit and  
Nicholson results.

W.H. Sinton, 1953; quoted by Manzel & Whipple (1955).

Then be a composite quantity, giving some  
weighted mean of the temperatures from various  
depths above and below the cloud ~~layer~~

case, and but it gives some indication of the range of errors. Two measurements made on the dark side in 1927 give average temperature of  $227^{\circ}$  K., which appears significantly lower than the mean of their measurements made during consecutive four months in 1924. Thus the possibility presents itself that secular temperature changes occur in the level of the Cytherean atmosphere responsible for the radiation detected by thermocouple. Kuiper (1957) in comparing these bolometric results with temperatures obtained by spectroscopic means (see below), concludes that the emitting level detected by thermocouple is determined by the optical density of  $\text{CO}_2$  and not by the altitude of the cloud layer, as had been assumed by Petit and Nicholson. The bolometric temperatures would ~~refer~~ refer to a higher level than the cloud

It would be interesting to determine, for example, whether ~~measurable~~ differences in bolometric temperature exist between, for example, dark equatorial and bright polar regions.

On the other hand, the most likely cause for such convection is rapid rotation itself.

Was it Ross?

larger, and would arise in part from the  $10\mu$  CO<sub>2</sub> emission. This emission is known to be variable, as has been mentioned above, and the ~~possible~~ reality of secular ~~several~~ changes in the bolometric temperature appears more likely.

Ross (1927) took the approximate equality of night and day bolometric temperature to indicate that the period of rotation must be much less than the period of revolution; otherwise the illuminated hemisphere would grow much warmer than the dark hemisphere. ~~However,~~ This conclusion is not valid if violent inter-hemispheric connection exists.

## 2. Rotational fine-structure analysis

Molecular vibration bands show rotational fine-structure, which, if a Boltzmann distribution of energy

J. W. Chamberlain + D. P. Kniper, Op. D. 124: 399, 1956

levels is assumed, can be used to derive a ~~rotational~~ temperature for the molecule. If ~~exists~~ equilibrium exists between rotational and translational energies, the rotational temperature so derived will be the appropriate gas kinetic temperature.

Derivation of the rotational temperature requires a relation between the intensities of the rotational fine-structure features and the population of the lower energy levels. Using an optically thick Cylindrical model atmosphere which scatters radiation isotropically to obtain this relation, Chamberlain and Verner (1956) found a ~~rotational~~ temperature for the atmosphere of Venus of  $285^\circ \pm 9^\circ\text{K}$ . The CO<sub>2</sub> bands in the 8000 Å region were used.

This temperature is a mean temperature along the path travelled by the light received on

earth. From considerations of pressure  
in an adiabatic atmosphere  
broadening, Kuijper (1957) derived a temperature  
of  $320^{\circ}\text{K}$ . for the bottom of the layer  
emitting the  $\lambda 8000$  features. This temperature  
must arise from deeper layers in the atmos-  
phere than the composite bolometric tem-  
perature. But whether it applies to since  
Venus appears more and more featureless  
infrared light must come from higher altitudes than ultraviolet  
at longer and longer wavelengths, & the rota-  
tional temperature must apply to higher  
altitudes than the ultraviolet and visible  
cloud layer. If the temperature continues  
to increase with depth both the surface  
(Kuijper, 1957) and the <sup>visible</sup> cloud layer will  
have temperatures higher than  $320^{\circ}\text{K}$ .  
( $47^{\circ}\text{C}$ ). Thus many substances which are  
solid or liquid at the temperature of ter-  
restrial clouds will be liquids or gases  
at the temperatures of the Cytherean cloud

layer.

If the cloud layer is at  $T = 320^{\circ}\text{K}$ , and convective balance equilibrium ~~apply~~ holds down to the surface, the <sup>cloud</sup> layer need only be 4 km. high for the surface temperature to be above the boiling point of water. On the other hand there is no evidence that convective equilibrium does apply down to the surface; for all we know the clouds could be at ~~a very~~ such an altitude below ~~that~~ them lie ~~such~~ temperature inversion zones, or thermal layers, and so forth. At the present time ~~there seems to be insufficient data~~ for ~~to draw~~ a definite conclusion about surface conditions from the bolometric or rotational temperatures.

C. H. Mayer, T. P. McCullough, + R. M. Slonaker,  
Ap. 8. 12711, 1958

### 3. Radio observations

Radio measurements have been made of the intensity of radio emission from Venus. If one assumes ~~the~~ ad hoc that the signal is due to ~~the~~ black body radiation ~~from~~ <sup>Cytherean</sup> Venus, a brightness temperature can be derived. If the from the Planck distribution. assumption of black body emission is correct, the brightness temperature should be independent of frequency.

Observations at 3.15 cm by Meyer, McCullough and Sloansker (1958) yield brightness temperatures ~~for~~ the beginning of their observing period of  $620^{\circ} \pm 110^{\circ}\text{K}$ ; and for the end of their observing period of  $560^{\circ} \pm 73^{\circ}\text{K}$ . Since the end of their observing period was near inferior conjunction, the lower temperature is consistent with the hypothesis that solar

For a cloud temperature of  $370^{\circ}\text{K}$ . and a surface temperature of  $600^{\circ}\text{K}$ . the resulting altitude difference for a convective atmosphere is 22 km. There is no a priori objection to a cloud layer 22 km. above the surface of Venus.

J. E. Gibson + R. D. McEwan, in "Paris Symposium on Radio Astronomy," R. N. Bracewell, ed., Stanford U. Press, 1959, p. 50

radiation is the ultimate source of energy for the emission. If the difference in temperature is statistically significant, it indicates that the 3.15 cm. emission does not come from a level where violent inter-hemispheric convection exists.

Two measurements at 9.4 cm. by the same workers give brightness temperatures of  $430^{\circ} \pm 215^{\circ}$  K. and  $740^{\circ} \pm 370^{\circ}$  K., the mean of which is near the 3.15 cm. temperatures. On the other hand, Gibson and McEwan (1959) at 0.86 cm. derive a Venna brightness temperature of  $410^{\circ} \pm 160^{\circ}$  K.

If we disregard the <sup>one low</sup> ~~4.7~~ measurement at 9.4 cm. the limited data available suggests an increase in apparent temperature with wavelength. This is a characteristic of non-thermal

~~In this case the derived apparent temperatures~~  
~~then~~  
~~give no information about surface temperature.~~

energy sources and resembles the situation recently found for Jupiter.<sup>41</sup> Explanations of the ~~radio~~ emission range from volcanic shock waves to Jovian van Allen belts, but there is no acceptable theory at present. The existence of a Cytherean Van Allen belt is by no means unlikely, and the proximity of Venus to the sun would increase the ~~atmospheric~~ injection rate of charged particles over the terrestrial value. However, with this explanation, the difference in temperatures between ~~merely~~ <sup>at 3.15 cm</sup> inferior conjunction and ~~and~~ <sup>should not</sup> ~~of~~ ~~in~~ superior conjunction cannot be significant; because against that from terrestrial experience, charged drift should cause charged particles trapped in the Cytherean magnetic field to <sup>should drift</sup> move through  $360^\circ$  in longi-

On the other hand if the temperature difference is significant, the very long <sup>azimuthal</sup> ~~azimuthal~~ time would suggest an upper limit on the azimuthal drift time and an upper limit on the time for particles to be scattered out of the belt could be obtained. These figures would provide much information on the "geophysical" environment of Venus.

tude in a few days at most. Radio reflections from Venus ~~could~~ <sup>be done from</sup> give would be capable of providing information on the electron density distribution in the Cytherean atmosphere. With a terrestrial value for the Cytherean magnetic field radio emission from the Venus Van Allen belts could then be calculated.

#### 4. Theoretical surface temperatures

From the <sup>value of the</sup> solar constant it is easy to derive that the mean surface temperature on the bright side of an airless planet which always keeps the same face towards the sun is

$$T_s = \frac{392}{\sqrt{a}} (1 - A)^{\frac{1}{4}} \text{ °K.} \quad (6)$$

where  $a$  is the distance of the planet from the sun in astronomical units, and  $A$  is the <sup>effective</sup> visual albedo of the planet.

$$\frac{392}{\sqrt{0.72}} = +62^\circ K$$

$$\frac{277}{\sqrt{0.72}} = 327^\circ K.$$

$$(1 - 0.64)^{\frac{1}{2}} = (0.36)^{\frac{1}{2}} = (0.60)^{\frac{1}{2}} = 0.775$$

$$e^{-0.71} = (0.29)^{\frac{1}{2}} = (0.538)^{\frac{1}{2}} = 0.732$$

An intermediate value never  $T > \text{then } T_1$   
is most likely.

For a rapidly rotating planet, the energy is distributed over four times as much area, so the temperature is  $4^{1/2} = \sqrt{2}$  less:

$$T_2 = \frac{277}{\sqrt{\alpha}} (1 - A)^{1/2} \text{ "K.} \quad (7)$$

For Venus, the mean value of  $\alpha$  is 0.72 A.U.; since the eccentricity of the orbit of Venus is only 0.007 the true value of  $\alpha$  never varies appreciably from this value. The effective visual albedo of Venus lies between 0.64 and 0.71 (Vilmer, 1957).

Hence,

$$358^{\circ}\text{K.} > T_1 > 338^{\circ}\text{K.} \quad (8)$$

and

$$254^{\circ}\text{K.} > T_2 > 240^{\circ}\text{K.} \quad (9)$$

Since it is not definitely established ~~that~~ Venus is rapidly ~~slowly~~ rotating, it is not possible to state with confidence whether  $T_1$  or  $T_2$  is more appropriate. Intermediate values are, of course, possible.

R. Wildt, Ap. J. 91: 266, 1940

Now of course Venus is not an airless planet. Black-body radiation emitted by the surface will be absorbed in the atmosphere, and reradiated to the surface. This so-called greenhouse effect should be more efficient on Venus than on the earth because of the great abundance of carbon dioxide on Venus.

An ingenious method of computing the magnitude of the <sup>CO<sub>2</sub></sup> greenhouse effect was indicated by Wilds (1940). An upper limit to the surface temperature,  $T_s$ , can be derived from the ~~constant~~ energy balance equation,

$$(1 - \epsilon) \sigma T_s^4 + \epsilon \sigma T_1^4 = \epsilon \sigma T_1^4 \quad (10)$$

in which  $\epsilon$  is the emissivity of the CO<sub>2</sub> atmosphere;  $\sigma$  is the Stefan-Boltzmann

constant;  $T_A$  is the effective temperature of the atmospheric layer responsible for the outward emission; and  $T$  is the temperature on an airless planet, either  $T_1$  or  $T_2$ . Eddington states. The term on the left hand side of the inequality (10) is the ~~energy~~ <sup>energy</sup> ~~time~~ <sup>each second</sup> escaping ~~through~~ between the atmospheric CO<sub>2</sub> bands from ~~the~~ <sup>each</sup> square centimeter of surface; the first term on the right hand side is the incident solar energy <sup>flux</sup>; and the second term on the right hand side is the outward energy flux of the CO<sub>2</sub> atmosphere. Wildt extrapolated from experimental work that the ~~approximate~~ point value of the emissivity ~~of~~ <sup>of</sup> CO<sub>2</sub> for the Cylindrical atmosphere is  $\epsilon = 0.35 \pm 0.05$ . From the preceding discussion it is clear that the appropriate value of  $T_A$  is Nicholson and Petit's composite bolometric temperature,  $735^\circ$  to

$$2 \times 10^{-7} = 16 \times 10^3$$

$$0.70 T_s^4 = 338^4 - 0.30 \cdot 235^4 = 1.30 \times 10^{10} - \frac{0.30}{3.0} \times 3.0 \times 10^8$$
$$= 1.30 \times 10^{10} - 9.0 \times 10^7 = 1.21 \times 10^{10}$$
$$\bar{T}_s^4 = 1.73 \times 10^9; T_s = (17.3)^{\frac{1}{4}} \times 10^2 = 196^\circ K$$
$$T_s^4 = 1.84 \times 10^{10}, T_s = (184)^{\frac{1}{4}} \times 10^2 = 368^\circ K.$$

$$0.70 T_s^4 = 358^4 = 1.64 \times 10^{10}, T_s^4 = 2.34 \times 10^{10}, T_s = 392^\circ K.$$
$$0.60 T_s^4 = 1.30 \times 10^{10}, T_s^4 = 2.17 \times 10^{10}, T_s = 388^\circ K.$$

~~$$0.60 T_s^4 = 1.64 \times 10^{10}; T_s^4 = 2.74 \times 10^{10}; T_s = 407^\circ K.$$~~

~~$$0.70 T_s^4 = 240^4 - 0.30 \cdot 235^4 = 3.32 \times 10^9 - 9.0 \times 10^7$$~~~~$$0.70 T_s^4 = 3.23 \times 10^9, T_s^4 = 4.02 \times 10^9; T_s = (40.2)^{\frac{1}{4}} \times 10^2 = 261^\circ K.$$~~

~~$$0.70 T_s^4 = 254^4 - 9 \times 10^7 = 4.17 \times 10^9 - 9.0 \times 10^7 = 4.08 \times 10^9$$~~~~$$0.70 T_s^4 = 5.84 \times 10^9; T_s = (58.4)^{\frac{1}{4}} \times 10^2 = 277^\circ K.$$~~

~~$$0.60 T_s^4 = 240^4 - 0.40 \cdot 235^4 = 3.32 \times 10^9 - 0.40 \times 3.0 \times 10^8$$~~~~$$= 3.32 \times 10^9 - 1.2 \times 10^8 = 3.20 \times 10^9$$~~~~$$T_s^4 = 5.33 \times 10^9; T_s = (53.3)^{\frac{1}{4}} \times 10^2 = 271^\circ K$$~~

~~$$0.60 T_s^4 = 254^4 - 0.40 \cdot 235^4 = 4.17 \times 10^9 - 1.2 \times 10^8 = 4.05 \times 10^9$$~~~~$$T_s^4 = 6.75 \times 10^9; T_s = (67.5)^{\frac{1}{4}} \times 10^2 = 287^\circ K$$~~

$240^{\circ}\text{K}$ . In Table I we have computed the surface temperatures resulting from the range of the discussed parameters.

Table I

Surface Temperatures on Venus	Slowly rotating	Rapidly rotating	Slowly rotating	Rapidly rotating
	$T_1 =$	$T_4 =$	$T_2 =$	$T_3 =$
$T_A = 235^{\circ}\text{K}$ .	$338^{\circ}\text{K}$ .	$358^{\circ}\text{K}$ .	$240^{\circ}\text{K}$ .	$251^{\circ}\text{K}$ .
$\epsilon = 0.30$	$368^{\circ}\text{K}$ .	$392^{\circ}\text{K}$ .	$261^{\circ}\text{K}$ .	$277^{\circ}\text{K}$ .
$T_A = 255^{\circ}\text{K}$ .	$383^{\circ}\text{K}$ .	$407^{\circ}\text{K}$ .	$271^{\circ}\text{K}$ .	$287^{\circ}\text{K}$ .
$\epsilon = 0.40$				
$T_A = 240^{\circ}\text{K}$ .	$368^{\circ}\text{K}$ .	$392^{\circ}\text{K}$ .		
$\epsilon = 0.30$				
$T_A = 240^{\circ}\text{K}$ .	$383^{\circ}\text{K}$ .	$407^{\circ}\text{K}$ .		
$\epsilon = 0.40$				

It is clear that <sup>the</sup> period of rotation of Venus is the critical factor in the determination of the surface temperatures.

If the period of rotation is much of the same order as about the the period of revolution, then so  $T \approx T_1$ , then the surface

is at or a little above the <sup>terrestrial</sup> boiling point of water. If, on the other hand, the period of rotation is much shorter than the period of revolution, so  $T \approx T_2$ , then the surface temperature is very similar to that on earth, the higher albedo compensating for the smaller distance to the sun. <sup>and the CO<sub>2</sub> greenhouse effect.</sup> In the absence of vast clouds of water vapor, there seems no appropriate substance to <sup>initial</sup> affect a more efficient greenhouse effect and so raise the temperatures above the values of Table I. If ~~the same~~  $T_s \approx 280^\circ\text{K}$ , the black-body emission is centered around  $10\mu$ , where water vapor is transparent, but if  $T_s \approx 400^\circ\text{K}$ , the Wien peak is at  $7.3\mu$ , which is within <sup>the very</sup> a strong water-vapor absorption band. Thus, if the planet is rotating rapidly, the presence of water

vapor should raise the surface temperature very little; but if the planet rotates ~~very~~ slowly, vast water clouds could rise to well above the terrestrial boiling point of water. <sup>Hence</sup> ~~there~~, it appears that if the 3.15 cm. brightness temperatures refer to surface black body emission, Venus must have <sup>and be rotating slowly</sup> vast water clouds. On the other hand if Venus has no vast water clouds, the radio emission must be nonthermal.

In the case of slow rotation the possible existence of ~~Ocean life~~ <sup>life</sup> on the Cthulian surface <sup>would be</sup> is marginal. But if Venus rotates rapidly, it would appear that the surface temperatures are near optimum for contemporary terrestrial organisms; <sup>and</sup> in this case also, it is much easier to imagine

<sup>H.C.</sup> Abing, "The Planets" Yale Cl. Press, 1952

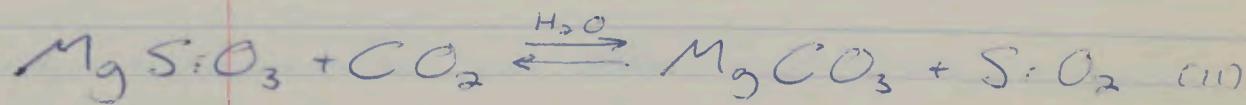
If, at equilibrium, the  $\text{CO}_2$  concentration increases; e.g., by vulcanism, the rate of carbonate sedimentation also increases. On the other hand if the  $\text{CO}_2$  concentration decreases, the reaction reverses, and silicate deposition increases.

the existence of indigenous Cytherean life-forms. Therefore detailed investigation of the temperature distribution and cloud convection of Venus is urgently needed in order to <sup>accurately</sup> determine the period of rotation. At the present writing, the existence of a banded cloud pattern (cf. p. 55, and the equality of day-night bolometric temperature, §C2, above) ~~suggests~~ <sup>hence</sup> rapid rotation, and ~~therefore~~  $T_s \sim 10^\circ\text{C}$ .

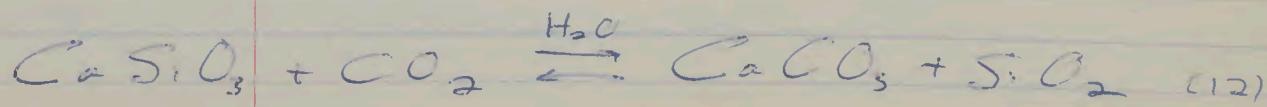
### E. Nature of the Cytherean Surface and the Origin of Carbon Dioxide

#### 1. The Urey equilibrium

Urey (1952) proposed that on a planet ~~with~~ <sup>having both surface</sup> silicates and <sup>surface</sup> water, the carbon dioxide partial pressure is maintained by equilibrium reactions such as



and



W. W. Rubey

D. E. Hutchinson

Now the partial pressure of  $\text{CO}_2$  above the Venus cloud layer, 0.2 atm,  $\gg 10^{-5}$  atm (cf. § B1, p. 29)

The partial pressures of CO<sub>2</sub> on the earth and Mars are within an order of magnitude of the room temperature equilibrium pressures<sup>(10<sup>-5</sup> atm.)</sup> resulting from reaction (11) and (12).

Rubey (195 ) has criticized the Urey equilibrium on the grounds that it is an oversimplified abbreviation of a complex series of geochemical processes. Nevertheless there seems little doubt that the overall effect is as if reactions (11) and (12) were operative (cf. Hutchinson, 195 ); the agreement of the Martian and terrestrial partial pressures with the equilibrium partial pressure is strong affirmative evidence.

Therefore, this apparent failure of the Urey equilibrium on Venus is a potential source of information on the Cytherean surface chemistry. The following explanations are possible:

a. Absence of water catalysis

Briegleb (1952) original explanation  
of the high  $\text{CO}_2$  content on Venus was  
the absence of  
~~the~~ the liquid water required to catalyze  
reactions (11) and (12) ~~as above~~.

Urey (1952) originally proposed that  
the high Cytherean  $\text{CO}_2$  abundance was  
due to an absence of the ~~liquid~~ water required  
to catalyze reactions (11) and (12). In this  
view few open bodies of liquid water exist  
on the surface of Venus, and the lower atmosphere  
is very dry. The surface would perhaps be  
best described as a wind-swept desert.

b. Insufficient exposure of surface ~~rocks~~ <sup>silicates</sup>

A second ~~possible~~ possibility is that  
all exposed silicates have already reacted  
to carbonates, and no further silicates  
are in contact with carbon dioxide. Two  
ways of accomplishing this are as follows:

D. H. Menzel + F. J. Whipple

A. Oparin + V. Fesenko, "The Universe," Foreign Languages Publishing House, Moscow, 1957, p. 224.

Oparin and Fesenko (1957) mention observations of Basabashov indicating specular reflection of sunlight from the Cytherean surface. The reflected image would be distorted and diffused by the intervening atmosphere and cloud layers. The existence of such a phenomenon would be strong evidence for the universal ocean. Similar observations have been reported for decades, but there has always been considerable reservations about their reliability (cf. Ross, 1928). This is an area meriting further study.

(1) Universal ocean

If ~~the~~ nearly all of the Cytherean surface were water-covered there would be little opportunity for reactions (11) and (12) to take place (Menzel and Whipple, 1955). In this view the surface of Venus is primarily an ocean of carbonated water, with perhaps an occasional limestone ~~calcareous~~-encrusted island. Surface temperatures would have to be much less than the boiling point of water. However since cold traps might exist between the surface and the visible cloud layer, a high surface vapor pressure of <sup>water</sup> would not necessarily imply spectroscopically-detectable amounts of H<sub>2</sub>O above the clouds ~~altogether~~. Naturally this view is correlated with "water clouds" layer.



H.C. Cheung, SSB

### (ii) Carbon dioxide excess

If the quantity of CO<sub>2</sub>s were so vast that reaction with all surface silicates still left an appreciable excess, the high carbon dioxide concentration could also be understood (Clay, 1959). ~~The most reasonable~~ One explanation for such an excess would be extensive recent volcanism; it is not impossible that ~~although~~ the Venus radio emission is of ~~igneous~~ volcanic origin. In this view the surface of Venus ~~would have~~ <sup>has</sup> appreciable water and features extensive igneous geomorphology.

### 2. Hydrocarbon-water equilibrium

The case of carbon dioxide excess requires an explanation of why such an abundance of CO<sub>2</sub>s was produced on Venus, and not the earth.

Henry Norris Russell. "The Atmosphere of Venus."  
Ap. J. 9 : 284, 1899

Schroeter (*Aphroditeoraphische Fragmente*, pp. 90ff.)<sup>1794</sup>  
first noticed that at near inferior conjunction  
the cusps of Venus' crescent project  
beyond the position they would occupy if  
Venus was merely an opaque atmospheric  
sphere, such as the moon. Tyman (*Am. J. Sci.*  
43 : 129, 1874) first observed the ~~cusps~~ to collapse  
into a ring.

Usual explanation is refraction in a clear  
atmosphere. But, if refraction, a very conspicuous  
refracted image of the sun ought to appear on  
that part of the ring furthest from the sun.  
Not observed. But specular reflection by Venus'  
surface might diminish contrast between sun's  
image + opposite part of crescent. Then  
a bright reflected image of the sun, of  
the same extent along the limb as the refrac-  
ted image, would be formed on the side of  
Venus near the sun. Brett contends  
specular image observed, but Russell says  
"the weight of evidence is strongly  
against it."

Russell proposes scattering by particles in  
the atmosphere above the cloud layer. The  
prolongation of the cusps occurs in that  
portion of the atmosphere  $\approx$  4000 ft. above the  
cloud layer. The height of the Cytherean  
atmosphere which can be seen by scattered  
light during terrestrial twilight is  
 $\approx$  7 miles above the cloud layer.

Notes from SSB Agenda Item 5.

Urey puts on Venus  $H_2O$  (polarization),  $N_2$  ( $N_2 + N_2^+$  night sky), +  $CO$  ( $CO^+$  bands in night sky + absorption bands in day sky).

Carbon compounds produced in poor atmospheres. If  $\frac{1}{2}$  excess of  $H_2O$ , most C compd. oxidized to  $CO_2$ , even  $H_2O$  remaining. If C compd. present in excess,  $H_2O$  used up, much  $CO_2$ , + excess C compd. remain.

Rate of escape of H from Venus very great. ~  $H_2O$  in atm. destroyed in very short time if not replenished from within. ... substantial source of subsurface moisture?

Partially-oxidized hydrocarbons for Venus clouds?

No Urey equiv. on Venus because

(1) extensive oceans preventing  $CO_2$ -silicate contact  
Giant planet, no water catalysis.

(2) overwhelming  $CO_2$  excess, so much remains even after complete reaction w. superficial silicate

Cleaning of Venus atmos. observed by French astronomer? Venus change: French = V yrs; Amer. - a few weeks.

NRL temps for Venus surface?

Comb. absorption coeff. of H on high-frequency side of Lyman limit.

$$\alpha_v = 6 \times 10^{-13} \left( \frac{v}{v_0} \right)^3 \text{ cm}^2 \text{ atom}^{-1} (\text{cycle/sec})^{-1}$$

Oriion nebula ~ 300 pc. away. For 1 atom/c.c., 300 pc.  
 $\Rightarrow 10^{21}$  atoms/cm<sup>3</sup>. ... table of optical depths corresponding to  $10^{21}$  atoms/cm<sup>3</sup> in lim of sight

$\lambda$	$T_H$	$T_{He I}$
912 Å	6000	--
504	1000	1000
100	0	20(?)
10	0.005	0.1

... for  $100i < \lambda < 912\text{\AA}$ , no observations of distant objects  
(Aller) Optical depth in center of Ly $\alpha$  ~  
 $10^6/\text{pc}^2$ . Radiation damping will make Ly $\alpha$   
completely black for a width of  $71$  for  $300\text{ pc}$ .  
distant source ... source must have radial vel.  
 $> 700 \text{ km/sec}$  to drift its Ly $\alpha$  out of observation.  
Dark objects w.  $T < 1500^\circ\text{K}$ . E.g. Dark companion  
of E Arietis; cool-off white dwarfs; cosmic  
background of radiation from galaxies w. very  
Ly $\alpha$  red shift.

Peculiar stars such as the R Coronae Borealis  
class of variable stars. They suddenly &  
unpredictably drop 5-8 magnitudes in the visible  
region. Dips last for order of weeks & occur  
intermittently at irregular intervals of several  
years. One explanation: obscuring cloud of solid  
part, possibly C, condenses in it's outer  
atmosphere.

Robert Ellis in Tasmania work at  $\sim 0.5 \text{ Mc/sec}$ .  
Det  $T > 10^6^\circ\text{K}$ .

Resolving power  $\propto \frac{1}{\Delta}$ : 100-fold increase in  
resolution at soft.

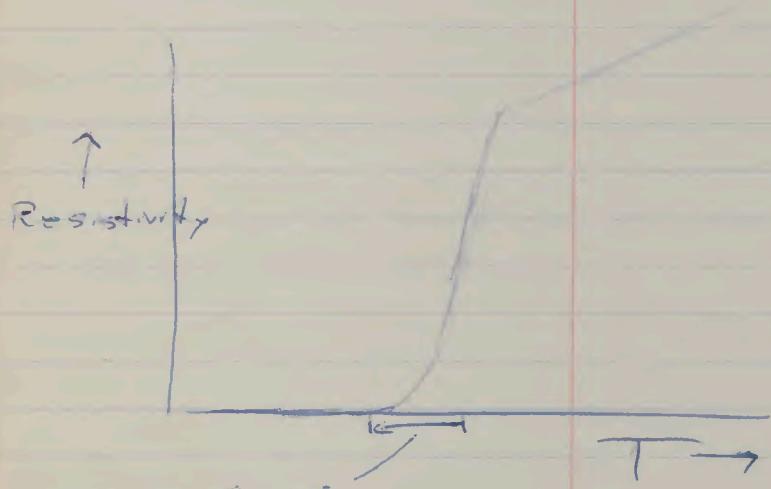
Hantzeijer (AFCTR): grazing incidence  
monochromator combined w. a Bendix mag-  
netically controlled photomultiplier w.  
X + uv-sensitivity tungsten cathode. On March,  
1959 he measured  $\lambda 303 \text{ He II}$  from a rocket  
at

$$0.2 \text{ ergs/cm}^2 \cdot \text{sec.}$$

[Factor of 50 w. Rens]

of Crayola

At low  $T$ , resistivity increases w. decreasing  $T$ ,  
semiconductor effect.  
At  $Sf = \frac{1}{3}$  cps, can detect  $6 \times 10^{-12}$  watts.



System maintained in this region so as  $\Delta T$   
gives  $\log \Delta R$ .

Cryogenic Engineering, Russell B. Scott,  
van Nostrand, 1959.

Ap. J. 127: 743

J. B. A. A. 66: 53

Proc. Roy. Soc. A 241: 37

Weldt, Ap. J. 86: 323, 1937

Cann. J' Ap. 16: 288, 1953; C.R. 248: 2069, 1959

Mem. B.A.A. 20: 32, 1916

M.N. 56: 166, 1896

Wright, JOSA 24: 1004, 1934. Color photos of dogs.

Fox, J.B.A.A. 62: 280 1952 Dug. markings during radio activity

Lord + Wright, J. Chem. Phys. 5: 692, 1937 G, Os band width.

3.43, 3.56, 3.67  $\mu$ .

Low eutectic points [Lange, Handbook<sup>9th ed.</sup> Chem.]

$\text{CaCl}_2$	-55 °C.
$\text{FeCl}_3$	-55
$\text{EuCl}_2$	-40
$\text{K}_2\text{CO}_3$	-37
$\text{KOH}$	-65
$\text{ZnCl}_2$	-62
$\text{MgCl}_2$	-33.6

} liquid water  
sols. above these  
temp.

Int. Crit. Tables, 3:367

For  $\text{MgCl}_2$ , extrapolation at 0 °C.:

$P_{\text{H}_2\text{O}} \approx 0.1 \text{ mm} \Rightarrow$  concentration  $\text{MgCl}_2$   
in 100 gm  $\text{H}_2\text{O}$  :  $\sim 75 \text{ gm}$ .

$\text{C}_3\text{O}_2$  absorption spectra: Thompson + Harley, P.R.S., 157:331, 1936  
 $\lambda 3350$  etc.

W.S. Boyle + K.F. Rodgers, Jr. - JOSA 49 166

